Yielding behavior of Martensitic Steel Sheet Containing Retained Austenite

Junya Tobata[1], Hidekazu Minami[2], Yuki Toji[3], Hideyuki Kimura[2], Shinjiro Kaneko[2]

[1] *Steel Research Laboratory, JFE Steel Corporation, 1 Kokan-cho, Fukuyama, Hiroshima, 721-8510 Japan.*
[2] *Steel Research Laboratory, JFE Steel Corporation, 1 Kawasaki-cho, Chuo-ku, Chiba, 260-0835 Japan.*
[3] *Steel Research Laboratory, JFE Holdings inc., Uchisaiwaichō, Chiyoda-ku, Tokyo 100-0011, Japan.*

Quenching and Partitioning (Q&P) steel, which utilizes the TRIP effect of retained austenite to improve the ductility of high strength steel sheets, is expected to become an important material for next-generation automotive structural parts. Although it has been reported that the yield strength of low carbon martensitic steels containing retained austenite, such as Q&P steel, is influenced by retained austenite, the mechanism has not yet been clarified in detail. Therefore, the purpose of this study is to analyze in detail the yielding behavior of low carbon martensitic steel sheets containing retained austenite. The chemical composition of the model steel used here was 0.18%C-1.5%Si-3.0%Mn (mass%). In order to control the carbon content in the retained austenite, various partitioning temperatures were used in the Q&P treatment. In Q&P steels, the elastic limit increased as the partitioning temperature increased. In contrast, the elastic limit of Q&T steels did not change depending on the tempering temperature. It was found that yielding of low carbon martensitic steel sheets containing retained austenite was caused by the stress-induced transformation of retained austenite. This study revealed that the main reason why the elastic limit of Q&P steels is lower than that of Q&T steels is because yielding of Q&P steels occurs by stress-induced transformation of retained austenite.

Keywords: *Q&P treatment, retained austenite, elastic limit, stress-induced transformation*

1. Introduction

High strength steel sheets are increasingly applied to automotive structural parts to reduce auto body weight so as to reduce CO_2 emissions while also improving vehicle crashworthiness. In particular, recent studies have reported that high yield strength steel sheets increase the crashworthiness of body frame parts [2)]. However, from the viewpoint of formability, it is generally necessary to increase tensile strength while maintaining the same elongation as conventional sheets in order to expand the application of high strength steels to a wider range of parts. For this reason, low carbon martensitic steel containing retained austenite, which utilizes the transformation-induced plasticity (TRIP) effect of retained austenite to achieve excellent ductility, have attracted attention in recent years.

One heat cycle which is capable of realizing a complex phase of martensite and retained austenite in steel is Quenching and Partitioning (Q&P) treatment [3)]. While it has been widely reported that Q&P steel sheets have a better balance of tensile strength and elongation than quenching and tempering (Q&T) sheets [4)], few studies have investigated the yielding behavior of low carbon martensitic steel sheets containing retained austenite.

In this study, the effects of the volume fraction of retained austenite and the carbon content in the retained austenite on the elastic limit of Q&P steel were investigated by intentionally changing the stability of the retained austenite in a model low carbon martensitic steel. Based on the results, the yielding behavior of low carbon martensitic steel containing retained austenite was discussed.

2. Experiment

The chemical composition of the steel used was 0.18%C-1.5%Si-3.0%Mn (mass%). As shown in **Fig.1**, (a) Q&P treatment and (b) Q&T treatment were conducted in an alumina fluidized-bed furnace. In the Q&P treatment, the steel sheets were annealed at 870℃ for 180s, which was in the austenite single-phase region. The annealed sheets were quenched at to 250℃, and then immediately heated to various partitioning temperatures. After holding for 600 s at the partitioning temperature, the sheets were water-cooled to room temperature. In the Q&T treatment, the sheets were annealed at 870℃ for 180s, followed by water-cooling to room temperature. Subzero treatment at -198℃ for 3.6×10^3s was conducted to minimize the retained austenite in the Q&T steel. The sheets were then heated, and tempering was carried out at various

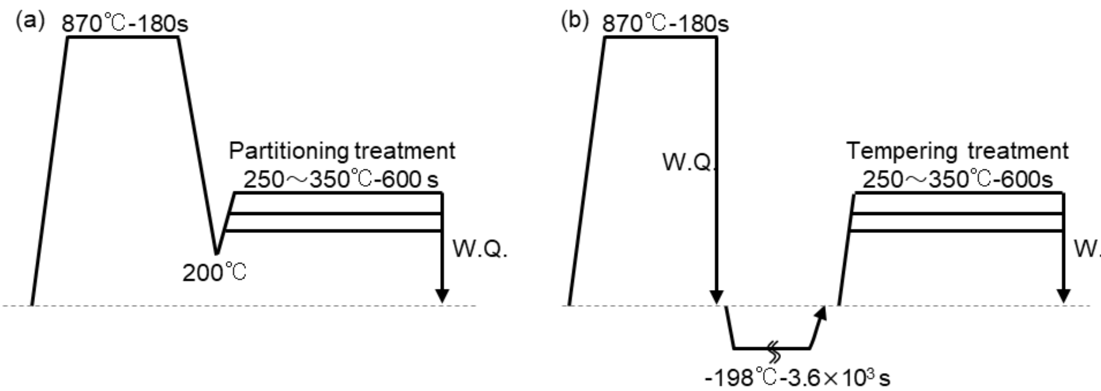

Fig.1 Thermal histories of (a) Quenching and Partitioning (Q&P) treatment and (b) Quenching and Tempering (Q&T) treatment.

temperatures for 600 s, followed by water-cooling to room temperature. To keep the retained austenite in the as-heat-treated condition, skin-pass rolling and leveling were not applied to any of the steel sheets. X-ray diffractometry was used to measure the volume fraction of retained austenite and the carbon concentration in the retained austenite of the samples. The tensile properties of the samples were evaluated by tensile tests using JIS No.5 tensile test piece (GL: 50 mm, GW 25 mm) at the cross head speed of 10 mm/min.

3. Results and Discussion

Table 1[1)] show the volume fraction of retained austenite and the carbon content in the retained austenite of each specimen for the Q&P steels. The Q&P steels contained roughly the same volume fraction of retained austenite but different carbon contents in the retained austenite. The volume fraction of retained austenite in the Q&T steels was found to be about 0 vol.%.

Fig.2[1)] shows a comparison of elastic limit of the Q&P steels and Q&T steels as a function of the partitioning temperature or tempering temperature. The elastic limit of the Q&T steels was basically constant at higher tempering temperatures, the elastic limit of the Q&P steels increased as the partitioning temperature increased and gradually approached that of the Q&T steels. These results revealed that the change in the elastic limit with increasing partitioning or tempering temperatures was clearly different in the Q&P steels and Q&T steels. Since the Q&T steels contained substantially no retained austenite, this implies that the elastic limit of the Q&P steels is strongly influenced by retained austenite in the martensitic matrix.

Haidemenopoulos et al. [5)] investigated the effect of the tensile test temperature on the yielding behavior of Q&T steel containing 9 vol% retained austenite using SNCM439, and reported that yielding depended on the stress-induced transformation of retained austenite at temperatures below 40℃. On the other hand, Tsuchida et al. [6)] reported that retained austenite in Q&P steel yielded first near 0.2% proof strength by in situ neutron diffraction experiments. Therefore, the dominant factors in the yielding of the Q&P steels with the partitioning temperatures of 250℃ and 350℃ was investigated. Olson [7)] reported that the increase of tensile test temperature increased the initial stress for the stress-induced transformation of retained austenite because of the improvement of mechanical stability of retained austenite, while the initiation stress of slip deformation of the matrix microstructure decreased. In the Q&P steels with partitioning temperature of 250℃ and 350℃, the elastic limit increased with increasing the tensile test temperature below 30℃, including room temperature. This result revealed that yielding at room temperature of the Q&P steels with partitioning temperature of 250℃ and 350℃ was caused by stress-induced transformation of retained austenite. Therefor the main reason why the elastic limit of Q&P steels is lower than that of Q&T steels is because yielding of Q&P steels occurs by stress-induced transformation of retained austenite.

4. Conclusions

The effects of the volume fraction of retained austenite and the carbon content in the retained austenite on the elastic limit of low carbon martensitic steel sheets were investigated, and the yielding behavior of quenching and partitioning (Q&P) steel sheets containing retained austenite was discussed. As a result, the following conclusions were obtained.

1. In Q&P steels, the elastic limit increased as the partitioning temperature increased. In contrast, the elastic limit of Q&T steels did not change depending on the tempering temperature.
2. The main reason why the elastic limit of Q&P steels is lower than that of Q&T steels is because yielding of Q&P steels occurs by stress-induced transformation of retained austenite.

Table 1 Effect of partitioning temperature on the volume fraction of retained austenite (γ_R) and carbon content in γ_R after Q&P treatment.

Partitioning temperature	Volume fraction of γ_R	Carbon content in γ_R
250℃	7 vol.%	0.3 mass%
300℃	7 vol.%	0.6 mass%
350℃	7 vol.%	0.7 mass%

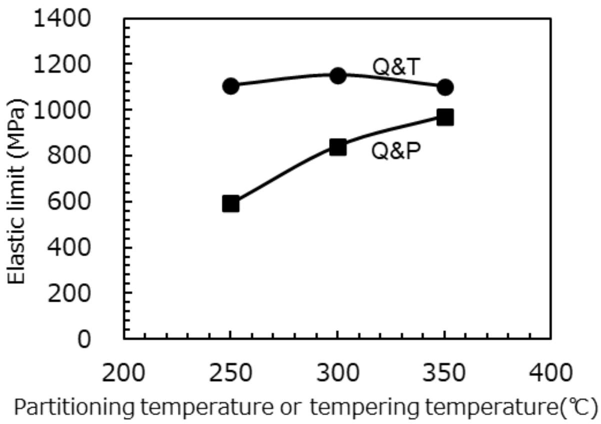

Fig. 2 Comparison of elastic limit between Q&P treated steels and Q&T treated steels as a function of partitioning temperature or tempering temperature.

References

1) J. Tobata, H. Minami, Y. Toji and S. Kaneko: ISIJ Int. (to be published).
2) K. Sato, T. Futatsuka, T. Sakaidani, S. Yoshika and Y. Tamai: Transactions of the Society of Automotive Engineers of Japan, Inc. 53(2022), 675) (in Japanese).
3) J. Speer, D.K. Matlock, B.C. De Cooman and J.G. Schroth: Acta Mater., 51(2003), 2611.
4) J.G. Speer, D.V. Edmonds, F.C. Rizzo and D.K. Matlock: Current Opinion in Solid State and Materials Science, 8(2004), 219.
5) G.N. Haidemenopoulos, M. Grujicic, G.B. Olson and M. Cohen: Acta Metallurgica, 37(1989), 1677.
6)N. Tsuchida, Y. Wada, H. Minami and Y. Toji: Mater. Sci. Eng.: A, 873(2023), 144989.
7) G.B. Olson, in Encyclopedia of Materials Science and Engineering (edited by M. B. Bever), Pergamon Press, Oxford, (1986), 2929.